
***Spacecraft Fire Experiment***

Advanced Exploration Systems Program

# Spacecraft Fire Safety Demonstration

***Joint CSA/ESA/JAXA/NASA Increments 47 and 48 Science Symposium***

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# International Topical Team

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  - Sandra Olson, Daniel Dietrich, Suleyman Gokoglu, Paul Ferkul, John Easton, Justin Niehaus

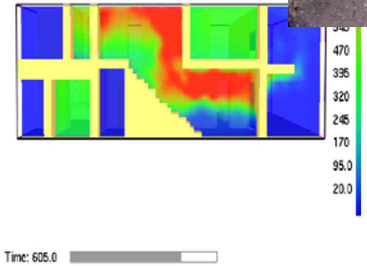
# Spacecraft Fire Safety Demonstration
# *Requirements and Goals*

- **Level 1 Requirements**
  - The project shall conduct an experiment on an International Space Station resupply vehicle after it leaves the ISS and before it re-enters the Earth's atmosphere.
  - The experiment performed on this vehicle shall meet a critical need for developing rational spacecraft fire safety strategy on future exploration vehicles.
- **Project Goals**
  - Conduct a spacecraft fire safety experiment on three flights of Orbital Science's Cygnus vehicle that investigates large-scale flame spread and material flammability limits in long duration low-gravity.
    - OA-6: March 2016 (launch date, operations occur ~2 months later)
    - OA-5: May 2016
    - OA-7: October 2016
- **Needs:**
  - Quantify the development and growth of a realistic fire for exploration vehicles
  - Determine low-g flammability limits for spacecraft materials

# How rapidly can a fire spread in low-g?

- **This question lies at the heart of the development of a fire safety strategy**
  - Terrestrial or spacecraft applications
- **Rate of fire growth impacts:**
  - Time to detect
    - Early detection reduces impact of fire, response strategy
  - Size of fire
    - Amount of fire suppression agent required
  - Heat release rate, fire spread to surrounding materials
    - Collateral damage
  - Emission of combustion products
    - Post-fire cleanup strategy and consumables

*NIST Full Scale Fire test*




*FAA full scale aircraft test*

**ALL terrestrial occupied structure types have been the subject of full scale fire tests (planes, ships, cars, trains, buildings, mines etc.)**

# Saffire Overview

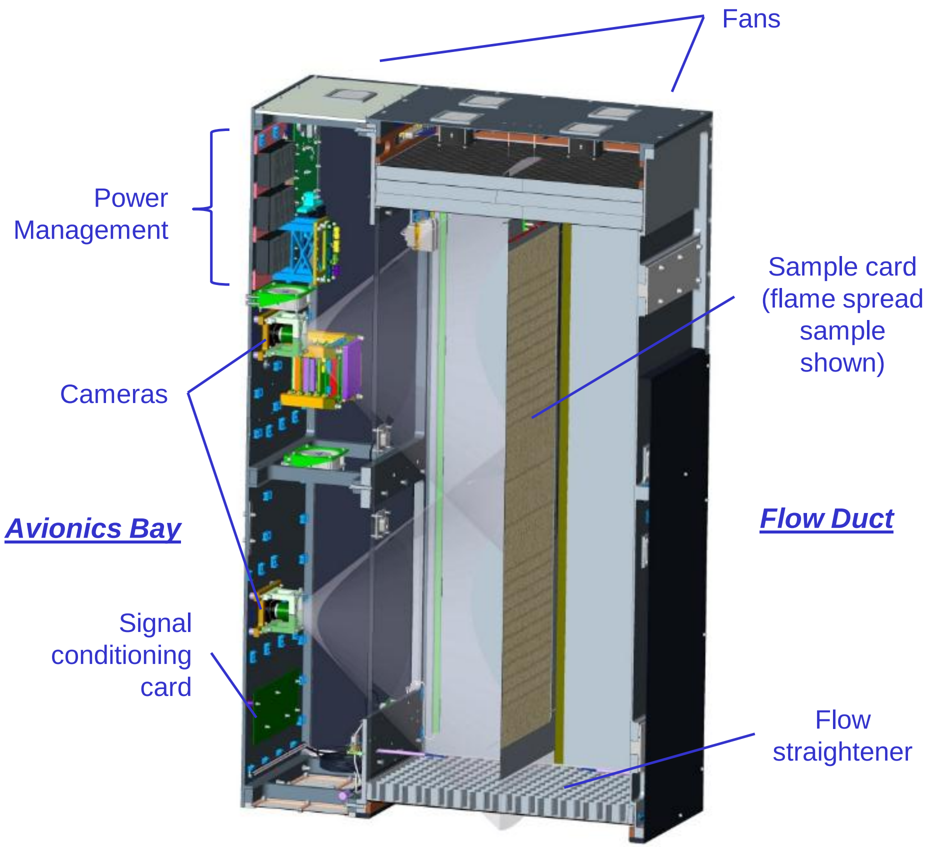
## Objectives:

- *Saffire-I*: Assess flame spread of large-scale microgravity fire
- *Saffire-II*: Verify oxygen flammability limits in low gravity
- *Saffire-III*: Assess flame spread of a large-scale microgravity fire (similar to Saffire-I)

## Data:

- Flame size, position, and spread rate (video)
- Flame intensity (radiometer)
- Flame stand-off distance (t/c)
- Flame/plume temperature (t/c)
- $O_2$, $CO_2$ concentrations

- *Data obtained from the experiment will be used to validate modeling of spacecraft fire response scenarios*
- *Evaluate NASA's normal-gravity material flammability screening test for low-gravity conditions.*




*Saffire module consists of a flow duct containing the sample card and an avionics bay. All power, computer, and data acquisition modules are contained in the bay. Dimensions are approximately 53- by 90- by 133-cm*

# Operations Concept

## *Pre-Launch*

*Saffire* Arrives at H100

*Saffire* Post Ship Checkout & Cygnus Interface Testing

Saffire Hand-Over for Cygnus Integration

Cygnus Integration & Power Continuity and Safety Inhibit Checks

*Saffire* Unpowered

Antares Launch

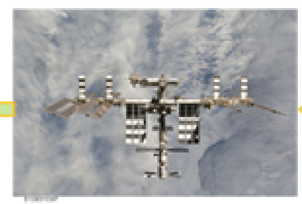
*Saffire* Unpowered

## *Unpowered*

*Inhibits Open*

ISS Rendevous, Prox Ops, and SSRMS Capture

*Saffire* Unpowered

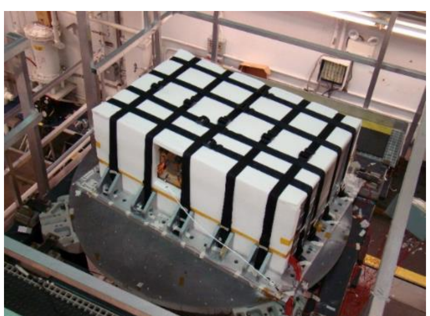


Cygnus Berthed to ISS

*Saffire* Unpowered
No crew interaction required.
PIA guidance on "trash" keep out zones around *Saffire*.

Cygnus Departs ISS

*Saffire* Unpowered

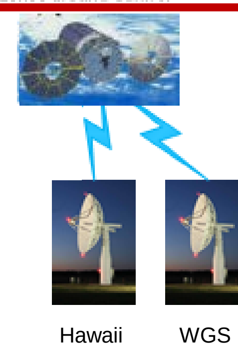


## *Powered*

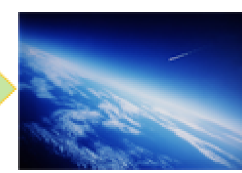
*Inhibits Closed*

Cygnus in Free Flight Outside ISS Safety Corridor

*Saffire* powered ON.
Autonomous Experiment Sequence Initiated




Cygnus remains in orbit up to 8 days to downlink *Saffire* data.



Cygnus Destructively Re-enters Atmosphere With *Saffire*

# Spacecraft Fire Safety Demonstration Research Objectives

- **Two major stakeholders in sample selection**
  - Scientific community
    - Large-scale low-gravity flame spread
    - Address both the "no ignition" and "no flame spread" criteria involved in passing standard material flammability testing
    - Materials can pass NASA-STD-6001 Test 1 because ignition energy is not sufficient to start the flame spread process
  - NASA Materials and Processes
    - If a material passes NASA Test 1 on the ground, will it pass the test in microgravity? (i.e. is the ground test the worst case scenario)
- **The long-term relevance to spacecraft fire safety applications depends on the careful and well-informed selection of the sample materials**
  - Relevance requires:
    - Scalability
    - Amenable to modeling

# Sample Selection Constraints

- **Dimensions and energy release**
  - 1 flame spread (large) samples (0.5 m x 1.0 m)
  - 9 material flammability samples (5 cm x 30 cm)
  - Thickness can be a maximum of 10mm
  - Total energy released can be a maximum of 54 grams of fuel (cellulose equivalent)
- **Data Acquisition (20 Gbits total)**
  - Thermocouples (6 total, shared by all 9 samples on Saffire-II)
  - Radiometer (four total, two on front and back)
  - Camera (front view)
  - Maximum run time of 6 minutes
- **Flow**
  - Flow rate range is 10-30 cm/s
  - Concurrent (upstream ignition) or opposed (downstream ignition)
- **Ignition power and system**
- **Long-term sample storage**

# Saffire I & III Samples

- Material was developed for microgravity flight experiments and has been studied extensively
  - Ground-based experiments
  - Modeling
  - Small-scale low-g experiments
- Cotton component simulates crew clothing
- Fiberglass substrate prevents cracking of charred fabric
  - Flame burns preferentially along the cracks
  - Alters the flow characteristics
  - Makes modeling considerably more difficult

# Saffire-II Sample Selection Goals

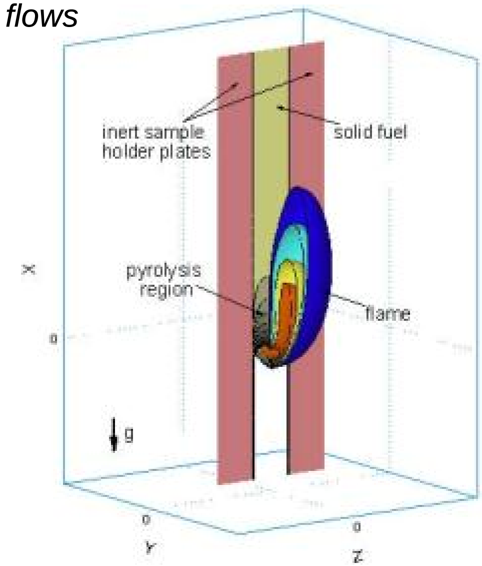
- **Build data sets on scalability of low-g fires**
  - Materials that have been tested in low-g at different length scales
- **Amenable to modeling**
  - Large, vehicle scale fire modeling
    - Impact on vehicle
    - Modeling of fire response
  - Details of low-g flame spread
- **Conclusive low-g flammability limit (Maximum Oxygen Concentration) data**
  - Flammability limit sample materials must to cross the flammability limit in 21% $O_2$
    - Requires approaches to alter flammability including: material thickness, heat loss (metal backing/matrix), radiative feedback (surface variation (grooves), inert (non-flammable) coatings

**Burning and Suppression of Solids (BASS)**

<u>2cm and 1cm Flat Samples</u>

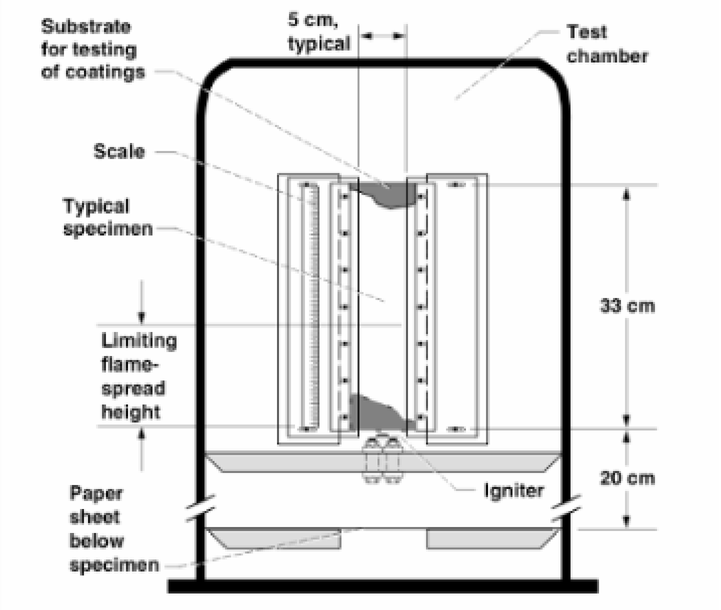
- SIBAL- cotton-fiberglass fabric
- Nomex- flame resistant material related to nylon
- Ultem - thermoplastic resins used in medical and chemical instrumentation

*Three-dimensional, time dependent upward flame spread in buoyant flows*



# Material Flammability Screening Test

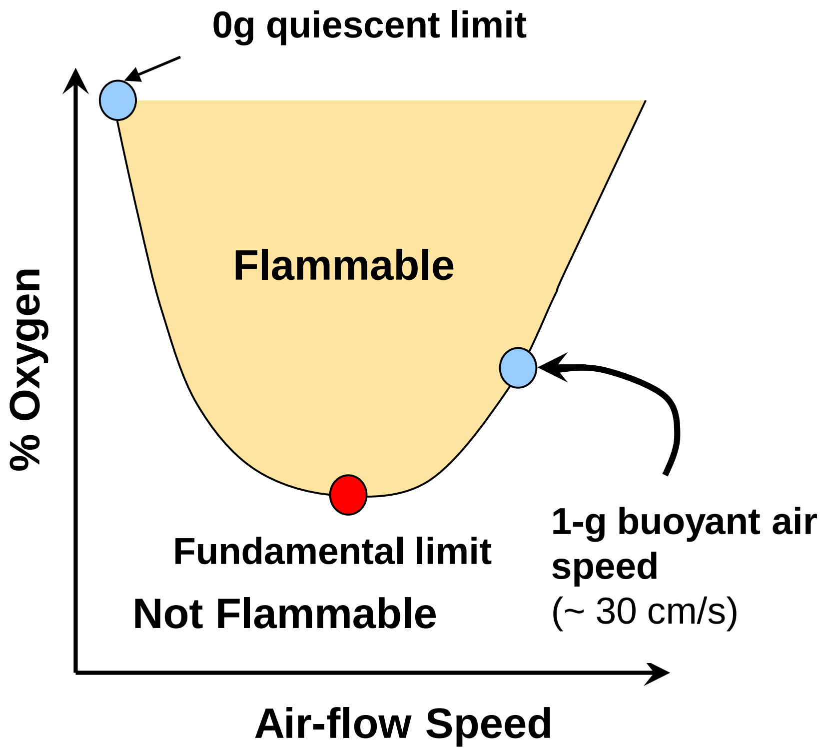
- NASA-STD-6001 describes the test methods used to qualify materials for use in space vehicles.
- The primary test to assess material flammability is Test 1: Upward Flame Propagation
- Materials "pass" this test if the flame self-extinguishes before it propagates 15 cm
- *Maximum oxygen concentration (MOC) is defined as the highest $O_2$ at which material passes Test 1*

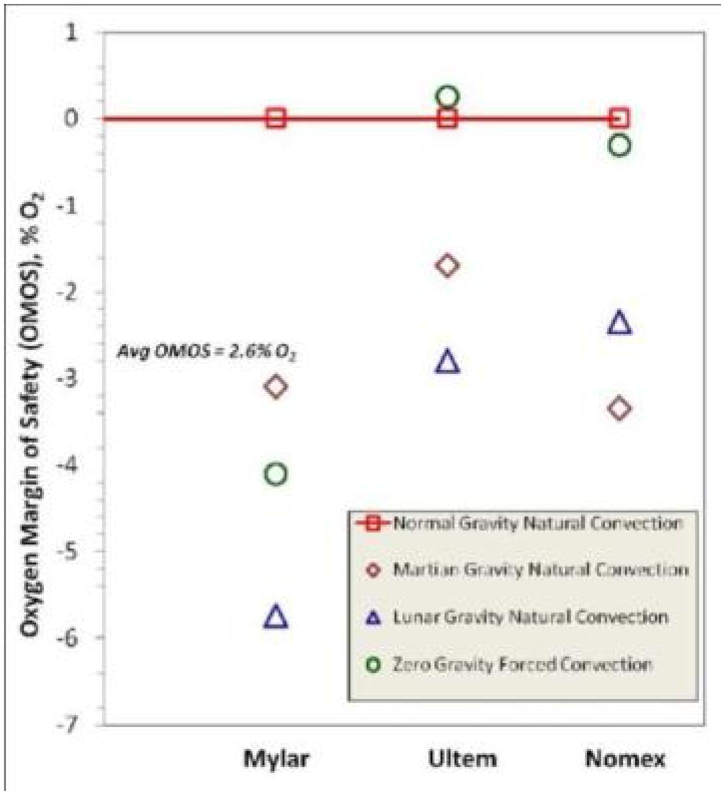



***Test 1 Apparatus***

# Low-g Maximum Oxygen Concentration

- Flammability limits determined by this test are strongly influenced by natural convection
  - Normal gravity flames induce a natural convective flow that transports oxygen to the flame *but also removes heat*
  - Forced convection in low-g transports oxygen to the flame but rate of heat removal is reduced

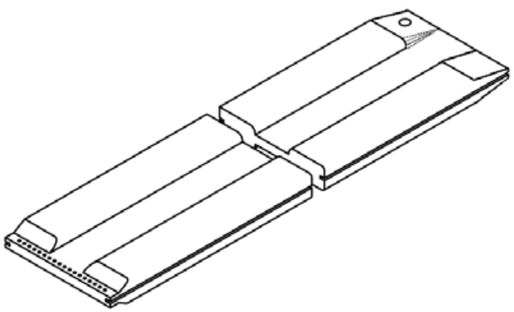


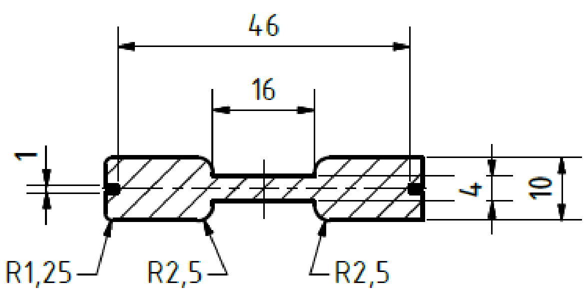



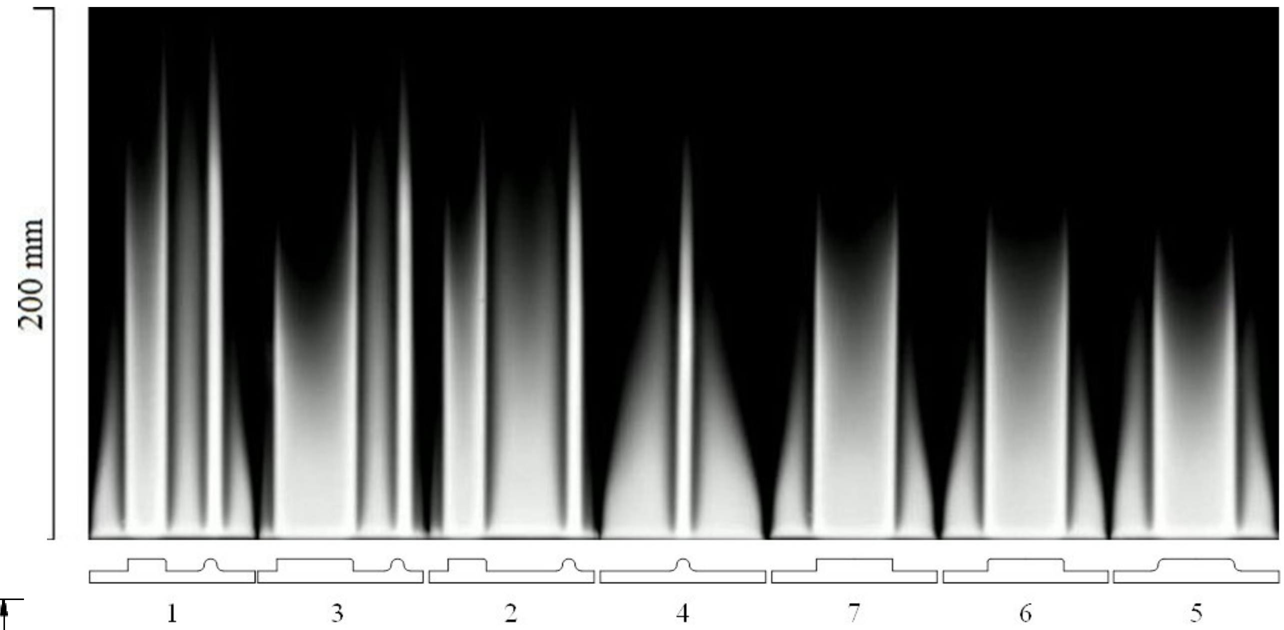

*Ferkul, P.V. and Olson, S.L., "Zero-gravity Centrifuge Used for the Evaluation of material Flammability in Lunar-Gravity," AIAA 2010-6260, 40th International Conference on Environmental Systems, Barcelona, Spain, July 11-15, 2010.*

# Saffire-II Samples

- International Topical Team members from Bremen, Germany are conducting ground tests of one of the samples to be flown on Saffire-II.
- This is a polymethyl methacrylate (PMMA) sheet with a machined ridges and grooves on the surface
- This will investigate the influence of surface structure on the spread rate of a low-g flame



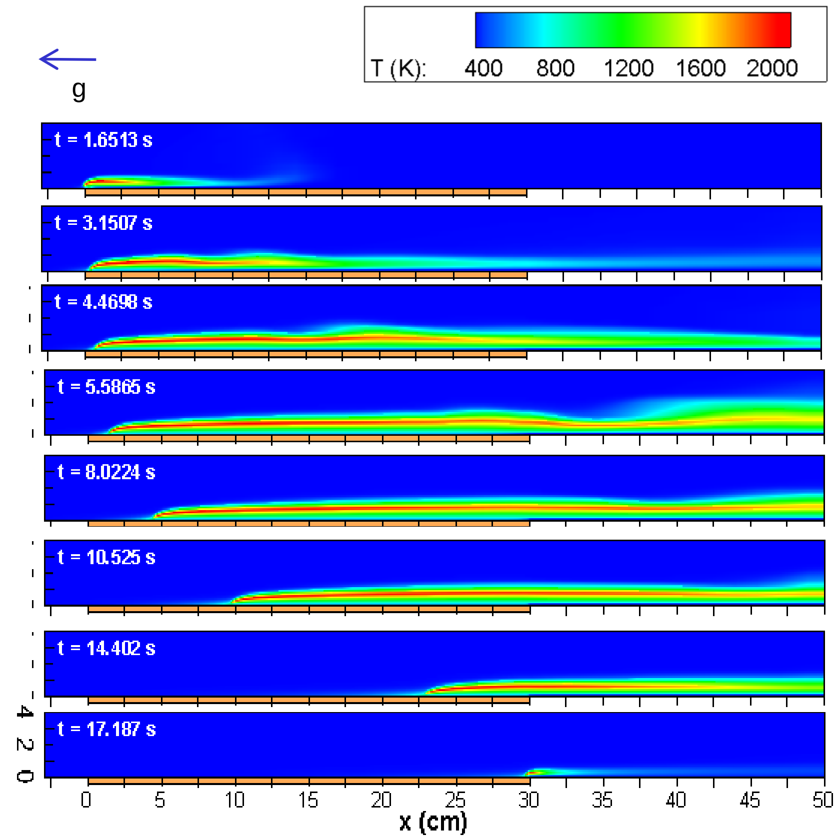



**Images obtained using an infrared (IR) camera of a flame on structured PMMA sample.** *The design of structures machined into the sample are shown below each image. The effect of edge curvature and type of structure on the flame is evident. These results were obtained in 1-g after 60 seconds for all images.*

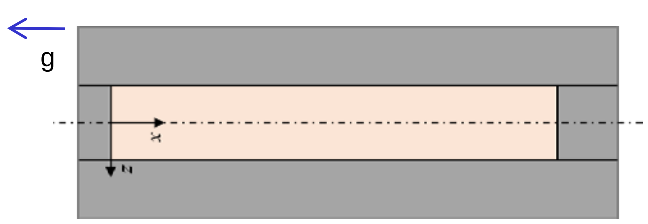
# Modeling

- Xiaoyang Zhao and Prof. James T'ien (Case Western Reserve University) are expanding the capability of an existing flame spread model to simulate Saffire test conditions.
- Data from Saffire-I, -II, and –III experiments will be compared to extended versions of these models.



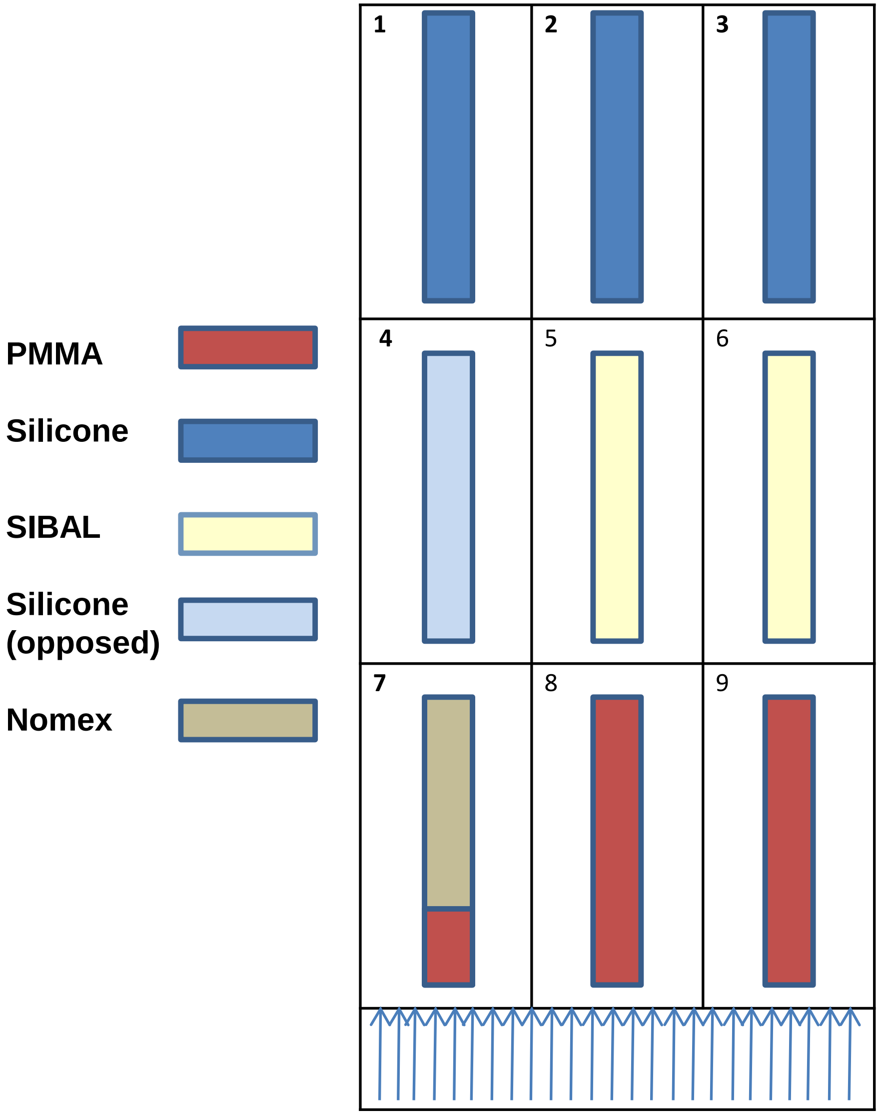

Temperature along center plan (colors) vs. time (top to bottom) for a buoyant flow condition. *(In low-g, Saffire conditions will be in forced flow.)*

*Buoyant flow sample is 5 cm wide by 30 cm long, sandwiched by metal plates*



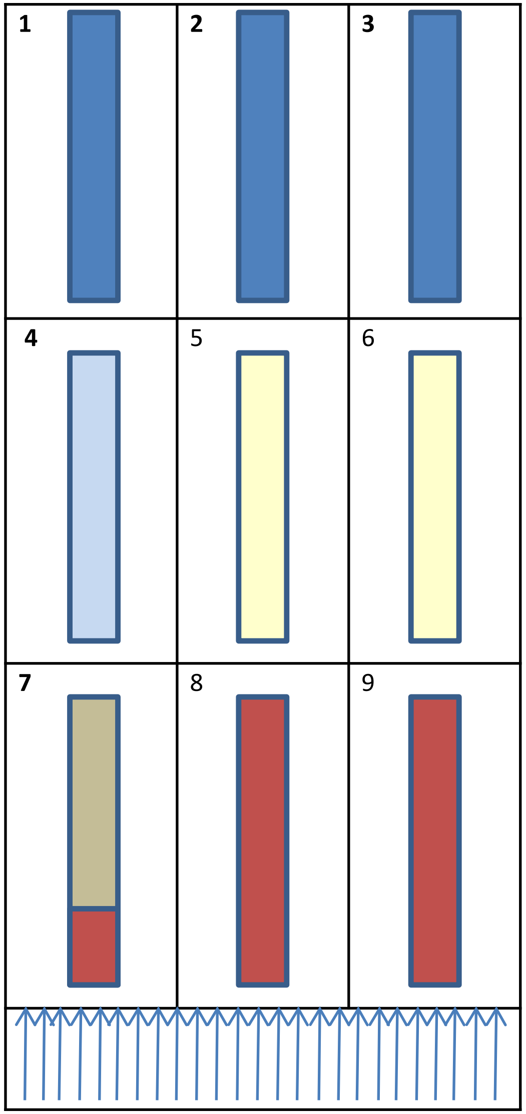
# Result: Saffire-II --- Array of 9 samples

- Samples are 5 cm x 29 cm
- Four different sample materials
  - Concurrent and opposed for Silicone
- Motivation
  - Previous low-g data (small scale)
  - Material flammability limits
  - NASA-STD-6001 Test 1
  - Spacecraft fire safety strategy



# Saffire-II: Array of 9 samples

| Sample # | Material | Sample Thickness | Flow (cm/s) | Igniter Position |
|---|---|---|---|---|
| Saffire-2-S1 | Flam limit 1 Silicone | 0.25 mm (0.010”) Silicone | 20 | Bottom |
| Saffire-2-S2 | Flam limit 2 Silicone | 0.36 mm (0.014”) Silicone | 20 | Bottom |
| Saffire-2-S3 | Flam limit 3 Silicone | 0.61 mm (0.024”) Silicone | 20 | Bottom |
| Saffire-2-S4 | Silicone down | 0.36 mm (0.014”) Silicone | 20 | Top |
| Saffire-2-S5 (Compares with Saffire-I) | SIBAL | N/A | 20 | Bottom |
| Saffire-2-S6 (Compares with Saffire-III) | SIBAL | N/A | Velocity of Saffire-III (30) | Bottom |
| Saffire-2-S7 | Transition 1: PMMA to NOMEX | N/A | 20 | Bottom |
| Saffire-2-S8 | Structured PMMA | 10 mm with tapered edge for ignition | 20 | Bottom |
| Saffire-2-S9 | PMMA | 10 mm with tapered edge for ignition | 20 | Bottom |

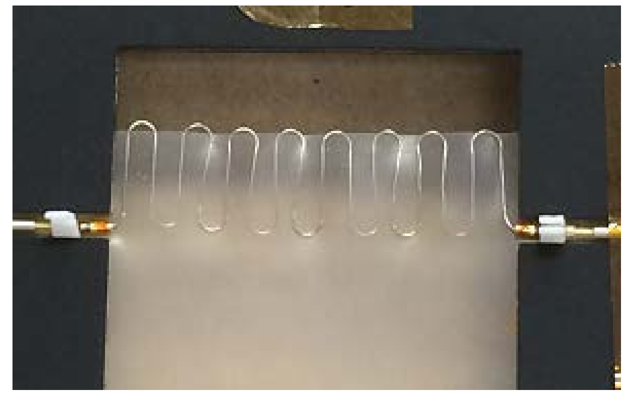


# Science Status
## *Saffire-II Sample Card*

- Populated and wired sample card for Saffire-II

- Igniter wire "loops" on a silicone sample
  - Space upstream of sample allows edge ignition

Flow



# Conclusions

- Through novel utilization of an existing carrier, Saffire has broken the path for a new research platform.
- Saffire tests exceed (in size) all prior low-gravity combustion testing by more than an order of magnitude, bringing the flames to a realistic scale.
- Saffire results will provide an important benchmark data set for future space craft fire safety design and analysis.